Economic Evaluations of Invasive Devices for Remote Cardiac Monitoring in Chronic Heart Failure: A Scoping Review

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ABSTRACT

Objectives. Heart failure presents a substantial global clinical and economic burden. While invasive hemodynamic and device-based remote monitoring effectively guide its management, their economic value across diverse healthcare systems remains incompletely characterized. This scoping review evaluates the cost-effectiveness of these distinct monitoring strategies.

Design and Methods. Following established scoping-review reporting guidelines, we searched PubMed and Scopus (March 2026) for original peer-reviewed economic evaluations (for example, cost-effectiveness or cost-utility analyses) of invasive cardiac monitoring or cardiac implantable electronic device remote monitoring in adult heart failure patients.

Results. Nineteen studies across 11 countries were included, divided into two categories: standalone invasive sensors (predominantly CardioMEMS, ten studies) and cardiac implantable electronic device remote monitoring (nine studies), the latter spanning standard platforms and advanced alerts (HeartLogic, TriageHF Plus). The first category showed pulmonary pressure-guided monitoring is cost-effective in high-income settings (United Kingdom, continental Europe, United States), though device pricing exceeded cost-effectiveness thresholds in Argentina. The second category consistently showed cost-neutral or cost-saving

outcomes compared with in-office follow-up, with the largest savings in resynchronization-defibrillator recipients. Advanced alert algorithms showed highly favorable economic profiles, although both lacked ideal comparators testing identical device platforms with the algorithm deactivated. These findings align with recent national health-technology guidance recommending both technologies.

Conclusions. Both technologies are economically advantageous for heart failure management across multiple healthcare systems. Future research should prioritize standardized health-economic modeling, explicit separation of technology subcategories with distinct comparators, randomized algorithm-on versus algorithm-off designs, and dedicated evaluations in low- and middle-income countries to guide equitable global deployment.

KEY LEARNING POINTS

WHAT IS ALREADY KNOWN

- Both invasive hemodynamic sensors and device-based remote monitoring are clinically effective tools for predicting and reducing heart failure hospitalizations.
- Despite their clinical efficacy, the economic value of these distinct monitoring strategies across diverse international healthcare systems and varying reimbursement frameworks has not been comprehensively mapped.

WHAT THIS STUDY ADDS

- Pulmonary artery pressure-guided management is consistently cost-effective in high-income healthcare systems, whereas in middle-income settings, economic viability relies heavily on local device price reductions.
- Cardiac implantable electronic device (CIED) remote monitoring is universally cost-neutral or cost-saving compared to in-office follow-up, generating the highest absolute savings in CRT-D recipients.
- Advanced alert algorithms layered on CIED platforms demonstrate highly favorable economic profiles, though future research requires standardized comparisons against active remote monitoring with the algorithm switched off.

INTRODUCTION

Heart failure (HF) affects an estimated 64 million people worldwide and is among the most frequent causes of hospitalization and premature mortality[1]. Its economic burden is substantial and dominated by recurrent hospitalizations, with indirect costs from lost productivity and informal caregiving amplifying the toll[2].

Despite advances in guideline-directed medical therapy, patients with chronic HF (CHF) remain at risk of decompensation episodes that go undetected until overt fluid overload requires emergency or inpatient care[3]. This reactive model of care is costly and carries a poor prognosis[4]. Remote monitoring technologies, comprising implantable hemodynamic sensors, transmission platforms integrated into cardiac implantable electronic devices (CIEDs), and multisensor alert algorithms, offer an alternative paradigm: earlier detection of deterioration enabling pre-emptive therapeutic adjustment[3].

Implantable hemodynamic sensors developed for HF include pulmonary artery pressure sensors (CardioMEMS, Cordella), left atrial pressure sensors (V-LAP, HeartPOD), and inferior vena cava sensors (FIRE1/NORM). CardioMEMS is by far the most extensively studied and most widely adopted, approved by the FDA in 2014 for NYHA Class III patients with a prior HF hospitalization on the basis of CHAMPION[5]; the indication was expanded in 2022 following GUIDE-HF[6] to NYHA Class II–III patients with elevated natriuretic peptides or a prior hospitalization, in both reduced (HFrEF) and preserved ejection fraction (HFpEF), at least in the US[6]. Remote monitoring of ICD and CRT-D devices through manufacturer platforms (Biotronik Home Monitoring, Medtronic CareLink, Boston Scientific LATITUDE, Merlin.net) is likewise widely adopted, mainly in HFrEF with left ventricular ejection fraction ≤ 35% (primary prevention)[7]. More recently, multisensor algorithms such as HeartLogic (Boston Scientific), HeartInsight (Biotronik) and TriageHF Plus (Medtronic) have entered clinical use[8], operating as analytical layers on existing CIED platforms.

Despite this growing clinical and regulatory evidence base, the economic value of these technologies across healthcare systems with differing reimbursement frameworks, hospitalization costs and willingness-to-pay thresholds has not been comprehensively mapped, and they remain underused and subject to utilization constraints. A scoping review, which maps the breadth of the available evidence without the restrictive eligibility criteria of a systematic review, is therefore the appropriate methodology. This review aims to identify, categorize and synthesize the evidence on economic evaluations of invasive hemodynamic monitoring and CIED-based remote monitoring in HF, with attention to the technologies

evaluated, the healthcare-system contexts studied, the methodological approaches used and the key economic outcomes reported.

METHODS

Search Strategy

This scoping review was conducted in accordance with PRISMA-ScR guidelines, and the completed PRISMA-ScR checklist is provided as Supplementary Material S1. The search was conducted on 24 March 2026 on PubMed (n=81 records) and Scopus (n=267 records). The PubMed string combined MeSH terms and free-text terms covering three conceptual domains: (1) heart failure (Heart Failure [Mesh], heart failure, cardiac failure, CHF, HFrEF, HFpEF, ventricular dysfunction); (2) invasive or device-based monitoring, comprising both generic descriptors and named technologies covering pulmonary artery pressure sensors (CardioMEMS, Cordella), left atrial pressure sensors (V-LAP, HeartPOD), inferior vena cava sensors (FIRE1), historical and discontinued platforms (Chronicle), impedance-based monitoring (OptiVol, CorVue), and multisensor algorithms (HeartLogic, TriageHF Plus, Heartinsight), together with the Prostheses and Implants [Mesh] heading; and (3) economic evaluation (Cost-Benefit Analysis [Mesh], Economics, Medical [Mesh], cost-effective, cost-benefit, cost-utility, health economics, economic evaluation, ICER, QALY, incremental cost, resource utilization, budget impact, hospitalization costs, healthcare utilization, willingness to pay). Reviews, systematic reviews, and meta-analyses were excluded via publication type filters. The Scopus search mirrored this structure, using proximity operators and the same

conceptual domains, restricted to title, abstract, and keywords. Full search strings are provided as Supplementary Material S2.

Eligibility Criteria

Studies were included if they: (1) enrolled adult patients with a diagnosis of HF; (2) evaluated any invasive cardiac monitoring technology or CIED-based remote monitoring system; (3) reported original economic data in the form of a cost-effectiveness analysis, cost-utility analysis, cost-benefit analysis, cost-minimization analysis, or cost-consequence analysis; and (4) were published as peer-reviewed original research articles. Search terms were formulated in English only, and no language filter was otherwise applied. Studies were excluded if they were reviews, meta-analyses, case reports, opinion papers, or study protocol publications without accompanying economic results.

Technology Classification Framework

For synthesis, eligible technologies were classified into two clinically grounded categories distinguished by implantation requirement, ejection-fraction applicability, and economic comparator.

The primary distinction between the two categories is the clinical rationale for implantation: standalone sensors (Category A) are implanted for the sole purpose of remote monitoring, whereas CIEDs (Category B) are implanted for an independent therapeutic indication onto which remote monitoring is added as a secondary function. As detailed below, this difference is what determines whether the cost of the implanted device is attributable to the monitoring strategy.

Category A comprises standalone invasive hemodynamic sensors that require a dedicated implantation procedure and are evaluated against standard care without the sensor (pulmonary artery sensors CardioMEMS [Abbott] and Cordella [Endotronix/Edwards], left atrial sensors V-LAP [Vectorious], PathFinder [Synkopi], Microtech [Medinol] and HeartPOD, and the inferior vena cava sensor NORM [FIRE1]); these are approved or evaluated irrespective of ejection fraction and therefore include also HFpEF scenario.

Category B comprises CIED-based remote monitoring, which operates on devices already implanted for an independent indication (ICD or CRT-D for arrhythmia prevention or cardiac resynchronization, almost exclusively in HFrEF with LVEF ≤35%), and includes (i) standard commercial transmission platforms (Biotronik Home Monitoring, Medtronic CareLink, Boston Scientific LATITUDE, Abbott/St. Jude Merlin.net) evaluated against conventional in-office follow-up, and (ii) advanced alert algorithms layered on existing CIED platforms (HeartLogic, TriageHF/TriageHF Plus, HeartInsight, OptiVol, CorVue), for which the ideal comparator is standard remote monitoring with the algorithm switched off; accordingly, these analyses evaluate the incremental cost of the monitoring strategy above a shared device-implant baseline rather than the cost of the implanted device itself. The two categories were kept separate because their comparators differ fundamentally (standard care without any device vs in-office follow-up with an existing CIED), making pooled ICER estimates non-comparable; this taxonomy is consistent with NICE's separate appraisal programs for invasive hemodynamic monitoring (HTG769) and CIED-based remote monitoring (HTG730).

Economic Analysis Frameworks

Eligible studies included those using standard health economic evaluation frameworks: cost-effectiveness analysis (CEA), which compares costs to clinical outcomes (e.g., cost per hospitalization avoided); cost-utility analysis (CUA), which relates costs to outcomes adjusted for quality of life, typically expressed as cost per quality-adjusted life year (QALY); cost-benefit analysis (CBA), which converts both costs and benefits into monetary terms to assess net economic gain; cost-minimization analysis (CMA), which identifies the least costly option when outcomes are assumed to be equivalent; cost-consequence analysis (CCA), which presents costs and multiple outcomes separately without aggregating them into a single metric; and headroom analysis, which estimates the maximum price or cost at which a new technology would still be considered cost-effective. Commercial headroom analysis, as applied by de Graaf et al.[9] in the REMOTE-CIED evaluation, calculates the maximum reimbursable price at which a new technology would remain cost-effective at a defined willingness-to-pay threshold, given its observed clinical effect on a primary outcome (typically hospitalization). Rather than producing a fixed incremental cost-effectiveness ratio (ICER), the approach yields a price ceiling expressed in monetary units per patient over a defined time horizon, intended to be more directly usable in payer–manufacturer pricing negotiations than a conventional ICER. Commercial headroom analysis was retained within the eligibility criteria of this review because it produces decision-relevant economic information equivalent in policy purpose to conventional cost-effectiveness frameworks, and because excluding it would have artificially restricted the evidence base for CIED-based remote monitoring in continental European healthcare systems.

Regulatory Context

In addition to the peer-reviewed literature identified through the database search, NICE HealthTech guidance documents (HTG769 and HTG730) and their accompanying resource impact reports were identified by manual search of the NICE website (nice.org.uk) and are referenced in the Discussion as policy context. These documents are health technology assessments produced by a regulatory body and do not meet the peer-reviewed eligibility criteria applied to the 19 primary studies; they are not included in the qualitative evidence synthesis but are referenced as contextual documents that provide a single-payer appraisal reference standard for interpreting the international economic evidence base.

Study Selection and Data Extraction

Titles and abstracts were screened by two reviewers (AC and FN), followed by full-text assessment. In addition, the reference lists of all reports included after full-text assessment were screened manually by the same two reviewers, and any report meeting the eligibility criteria was added to the review. The sixteen reports excluded at the full-text screening stage, are listed in Supplementary Material S3. Data extraction was performed independently by AC and FN using a standardized form capturing: first author, year, country, study design, technology evaluated, sample size, comparator, type of economic analysis, perspective, time horizon, discount rate, primary and secondary outcomes, key cost-effectiveness results (ICER [Incremental Cost-Effectiveness Ratio], incremental costs, incremental QALYs where available), and funding source. Discordances between the two reviewers were resolved through discussion. Although a formal critical appraisal is not mandated for scoping reviews, a structured risk-of-bias assessment of the 19 included studies was nevertheless performed independently by the two reviewers and is reported in full as

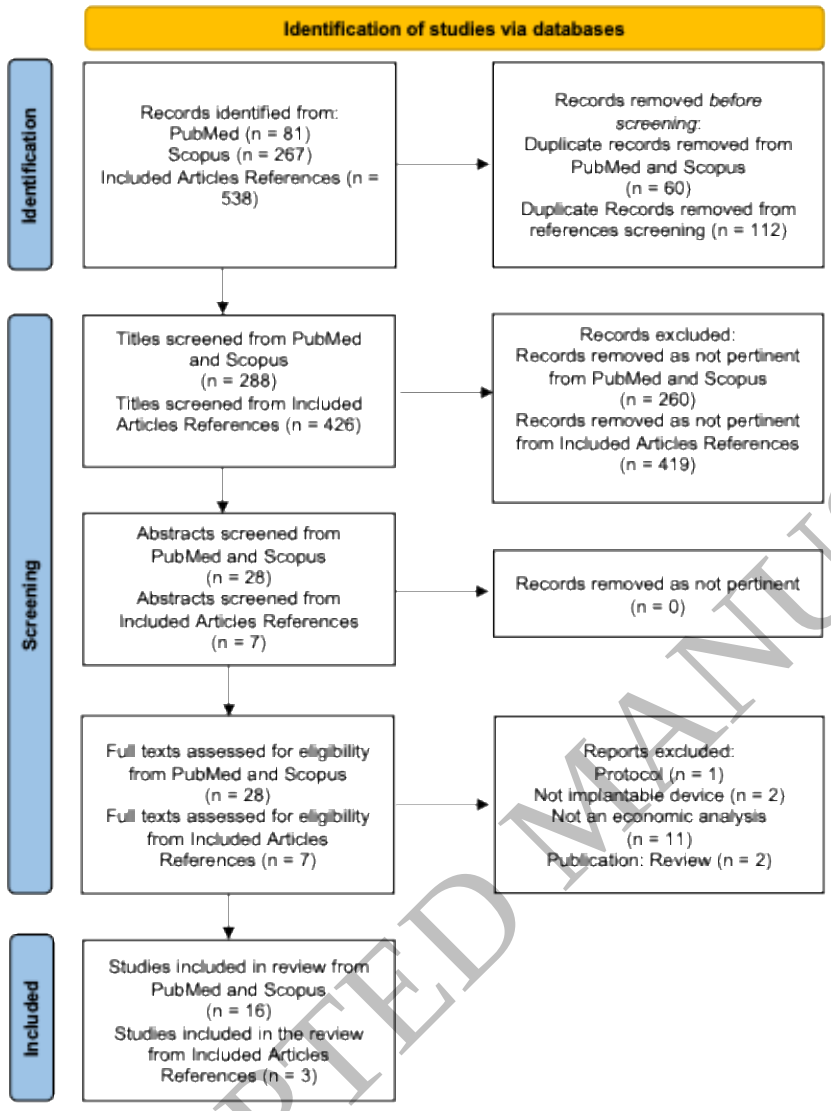
Supplementary Material S4; key methodological limitations identified by the study authors themselves are additionally described narratively.

RESULTS

Records Distribution

The combined PubMed and Scopus search retrieved 348 records. After duplicate removal, title and abstract screening, a total of 16 studies met the full eligibility criteria from the database search. Manual screening of the reference lists of these 16 reports yielded a further 538 references, of which three met the full eligibility criteria, giving a total of 19 studies included in this scoping review (PRISMA flow diagram, **Figure 1**). The included studies were published between 2013 and 2025, with 17 (89.5%) published from 2016 onward, reflecting the progressive maturation of the economic evidence base as clinical trial data for CardioMEMS and CIED remote monitoring platforms accumulated. All included studies and their core characteristics are summarized in **Table 1**, whereas **Supplementary Material S5** explores the details of each study.

Figure 1. PRISMA Flow-Diagram



Study Characteristics

Nineteen studies were included[10–21,9,22–24,8,25,26]. Studies were conducted in 11 countries (12 distinct country sets) across Europe, North America, and South America. Five studies used a decision-analytic Markov model with a hypothetical cohort[10,16,17,19,20]; three further Markov models used trial-derived parameters from CHAMPION or TRUST[12,14,21]; four were directly trial-based economic evaluations, with Mokri 2024[23] adding a lifetime Markov extrapolation

to its in-trial analysis[9,11,23]; five were prospective or retrospective observational cohorts[13,15,18,22]; Ahmed 2025[24] built a two-state lifetime economic model on individual patient-level data from a propensity-weighted real-world cohort; and one study applied a hybrid dynamic simulation, combining system-dynamics macrosimulation with discrete-event microsimulation, to project outcomes for the whole German NYHA class III population[26].

Notably, in category A (standalone invasive hemodynamic sensors), no peer-reviewed economic evaluations were retrieved for other invasive hemodynamic monitoring devices, including left atrial pressure sensors (V-LAP [Vectorious Medical Technologies], PathFinder [Synkopi], Microtech [Medinol], HeartPOD), the inferior vena cava sensor NORM (FIRE1), or the historical Chronicle device (Medtronic). The pulmonary artery sensor Cordella (Endotronix/Edwards Life Sciences) appeared only within a mixed CardioMEMS/Cordella European cohort in which costs were not reported separately by device type[25], so no device-specific economic estimate is available for it either. Likewise, in category B (CIED-based remote monitoring) only CIED-resident algorithms HeartLogic and the Medtronic TriageHF family have been evaluated from an economic standpoint, while no data are available in the literature for HeartInsight (Biotronik) and CorVue (Abbott/St. Jude). Impedance-based OptiVol alerts (Medtronic) were enabled within the remote arm of the MORE-CARE trial[8], but bundled inseparably with the transmission platform rather than evaluated as a distinct algorithmic layer, so no standalone economic estimate exists for them either. The economic evidence base is therefore currently confined, in practice, to CardioMEMS in Category A and to a subset of CIED platforms and two alert algorithms in Category B.

Overall, the most common type of economic analysis was cost-utility analysis (CUA; n=9[11,12,14,16,17,19,20,23,24]), followed by cost-consequence or cost-comparison analyses (n=7[8,10,13,18,21,25,26], the last of these being a population-level budget-impact simulation rather than a per-patient analysis), cost-minimization analysis (n=1[15]), cost-benefit analysis (n=1[22]), and a commercial headroom analysis (n=1[9]). Commercial headroom analysis, applied here only in the REMOTE-CIED evaluation, does not generate an ICER. Instead, taking the observed clinical effect of the technology as given, it calculates the maximum price at which that technology would still be cost-effective at a defined willingness-to-pay threshold, and expresses the result as a monetary ceiling per patient over a stated time horizon. It therefore answers the question "how much could a payer pay for this technology before it stopped being good value?" rather than "what does this technology cost per QALY gained?", and is intended to be directly usable in payer–manufacturer pricing negotiations. Discount rates varied from not applicable (short-horizon trial-based analyses) to 5% per annum, with most model-based studies using 3%–3.5% in line with national guidelines (**Supplementary Material S5**).

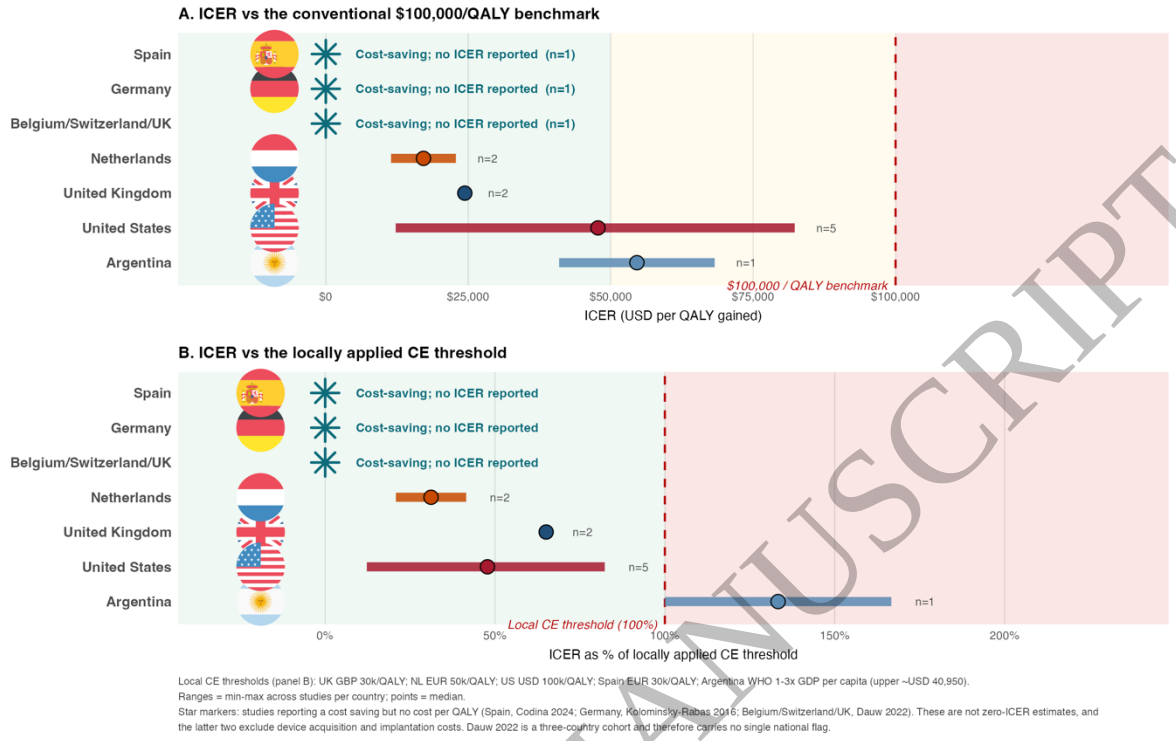
Category A: Standalone Invasive Hemodynamic Sensors (CardioMEMS)

Ten studies evaluated standalone pulmonary artery pressure sensors[12,14,16,17,19,20,22,23,25,26], all of which assessed the CardioMEMS HF System except one European cohort that combined CardioMEMS and Cordella recipients[25]. All data are summarized numerically in **Tables 1** and **Supplementary Material S5**. Three patterns dominate the evidence base.

First, in high-income settings with formal cost-effectiveness benchmarks, CardioMEMS consistently falls within accepted willingness-to-pay ranges: UK ICERs cluster at £19,274–

£19,761 per QALY[16,20], Dutch ICERs from the MONITOR-HF trial sit at €10,406 per QALY from a healthcare perspective and €20,753 per QALY from a societal perspective[23], and three independent US analyses span $12,262–$71,462 per QALY, all comfortably below the conventional $100,000/QALY benchmark[12,14,17]. A real-world Spanish cohort reported a positive net financial return emerging by year two and reaching €10,110 per patient by year five, driven by a 78% reduction in HF hospitalization rate[22]. Two further analyses reported cost reductions without deriving an ICER: a three-center Belgian, Swiss and UK cohort in which HF-related healthcare costs fell by approximately 40% (from €6,286 to €3,761 at 6 months and from €8,960 to €6,167 at 12 months) alongside a halving of HF hospitalizations[25], and a German dynamic simulation projecting 114,805 avoided hospitalizations and €522 million in avoided hospitalization costs between 2009 and 2021[26]. In both, device acquisition and implantation costs were excluded, so these figures represent gross hospitalization-cost offsets rather than incremental cost-effectiveness estimates. A summary visualization of country-specific CardioMEMS ICERs against the conventional $100,000/QALY (and corresponding 1-3x GDP per capita) cost-effectiveness benchmarks is provided in **Figure 2**.

Figure 2. CardioMEMS / PA pressure sensor cost-effectiveness across countries



Local CE thresholds (panel B): UK GBP 30k/QALY; NL EUR 50k/QALY; US USD 100k/QALY; Spain EUR 30k/QALY; Argentina WHO 1-3x GDP per capita (upper ~USD 40,950).
Ranges = min-max across studies per country; points = median.
Star markers: studies reporting a cost saving but no cost per QALY (Spain, Codina 2024; Germany, Kolominsky-Rabas 2016; Belgium/Switzerland/UK, Dauw 2022). These are not zero-ICER estimates, and the latter two exclude device acquisition and implantation costs. Dauw 2022 is a three-country cohort and therefore carries no single national flag.

Much of the apparent cross-country ICER spread reflects methodological choices rather than true differences in clinical value. Three drivers can be identified consistently across analyses: device list price (£9,500 in the UK versus €12,397 in the Netherlands), discount-rate convention (uniform 3–3.5% in the UK and US versus a split 4%/1.5% rate in the Netherlands, the latter mechanically lowering ICERs), and the choice of perspective (healthcare versus societal).

Third, the only US analysis to report ejection-fraction subgroups identified materially more favorable economics in HFpEF ($47,768/QALY) than in HFrEF ($82,301/QALY), a clinically important signal in a population that currently has no alternative device-based monitoring option (Sandhu et al. 2016).

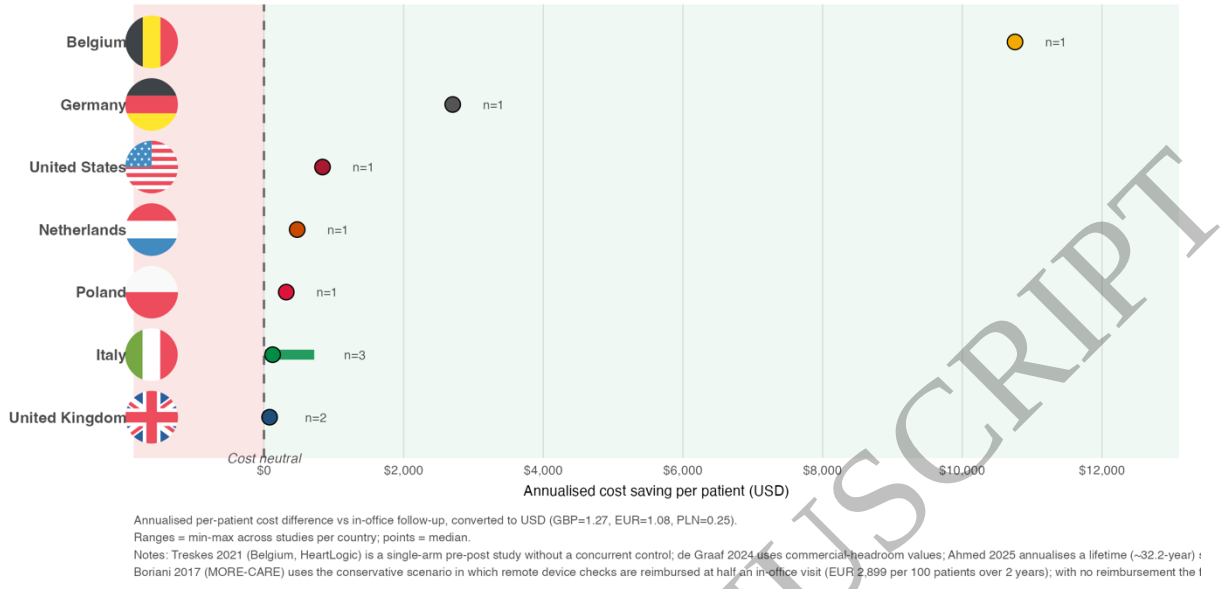
The single setting in which CardioMEMS is not cost-effective at current prices is Argentina[19] (Alcaraz et al. 2021), where modelled ICERs of approximately three to five times national GDP per capita exceed the WHO Commission on Macroeconomics and Health threshold of 1–3x GDP commonly applied locally; the authors estimated that a 10–25% device price reduction would be required to bring CardioMEMS into the cost-effective range, a finding directly relevant to pricing negotiations in similarly positioned middle-income healthcare systems. Taken together, the Category A evidence is internally consistent as PA pressure-guided management appears economically attractive across diverse high-income payers and underperforms only where device acquisition cost is large relative to local healthcare unit costs.

Category B: CIED-Based Remote Monitoring (Transmission Platforms and Advanced Alert Algorithms)

Nine studies evaluated CIED-based remote monitoring: seven examined standard transmission platforms versus conventional in-office follow-up[8–11,13,15,21], and two assessed advanced alert algorithms layered on existing CIED platforms (HeartLogic[18]; TriageHF Plus[24]). A summary visualization of country-specific is displayed in **Figure 3**.

Figure 3.

Figure 3. CIED-based remote monitoring: per-patient cost saving across countries



Annualised per-patient cost difference vs in-office follow-up, converted to USD (GBP=1.27, EUR=1.08, PLN=0.25).
Ranges = min-max across studies per country; points = median.
Notes: Treskes 2021 (Belgium, HeartLogic) is a single-arm pre-post study without a concurrent control; de Graaf 2024 uses commercial-headroom values; Ahmed 2025 annualises a lifetime (~32.2-year)
Boriani 2017 (MORE-CARE) uses the conservative scenario in which remote device checks are reimbursed at half an in-office visit (EUR 2,899 per 100 patients over 2 years); with no reimbursement the

Across this body of evidence, no study found remote monitoring to be economically inferior to in-office care (**Table 1** and **Supplementary Material S5**). The included Category B analyses encompassed time horizons ranging from 16 months in the trial-based EVOLVO analysis to lifetime Markov projections in the TRUST and TriageHF Plus models, and analytic perspectives spanning hospital, payer, and societal perspectives[9–11,13,15,18,21,24]. The economic outcomes most modelled were avoided heart-failure hospitalizations and avoided in-office device follow-up visits, with several analyses also incorporating reductions in inappropriate ICD shocks and emergency-department contacts[10,13]. Because the ICD or CRT-D in these analyses is implanted for an independent therapeutic indication and is present in both the remote-monitoring and in-office arms, the device acquisition and implantation cost is common to both comparators and does not enter the incremental cost of remote monitoring; the costs compared are those of the monitoring strategy itself (platform access, data transmission, and personnel/triage time) together with downstream events such as HF

hospitalizations, emergency-department contacts, in-office device checks, and inappropriate shocks. This contrasts with Category A, where the sensor is implanted solely for monitoring and its one-time implantation cost is therefore included in the incremental analysis. Three observations are clinically relevant.

First, although the Category B analyses captured both in-office device follow-up visits and HF-related hospitalizations on the cost side, the principal driver of economic benefit was in most analyses a reduction in HF-related hospitalizations rather than the replacement of routine outpatient device visits alone, in line with the clinical rationale for these technologies. The MORE-CARE randomized trial is the clearest exception: it found no reduction in HF or all-cause hospitalization (incidence rate ratio for HF hospitalization 0.97, 95% CI 0.74–1.29) yet still reported net savings of €2,899–€12,496 per 100 patients over two years, generated almost entirely by a 41% reduction in scheduled in-office visits[8]. Savings in Category B can therefore arise through either mechanism, and their relative contribution depends on the baseline event rate and on the intensity of the in-office follow-up schedule being displaced.

Second, in subgroup-resolved analyses, CRT-D recipients consistently generated greater absolute savings than ICD recipients. This finding likely reflects the higher baseline burden of HF events in patients with left bundle branch block, and the broader set of monitorable parameters available in CRT-D patients, resulting in larger absolute reductions in hospitalization-related costs[27].

Third, the absolute magnitude of saving varied substantially, from approximately £33 per patient over a decade in the UK Biotronik Home Monitoring model[10] to approximately £3,989

per patient over a lifetime in the UK TriageHF Plus analysis[24]. A methodologically distinct contribution came from the REMOTE-CIED commercial-headroom analysis[9], which quantified value in terms of the maximum reimbursement level compatible with cost-effectiveness (€881 per two years in the Netherlands, €5,005 in Germany).

Two studies evaluated advanced alert algorithms as a layer on top of the CIED transmission platform: HeartLogic in a multicenter Belgium/Netherlands/Switzerland pre-post cohort[18] (n=74) and TriageHF Plus in a UK propensity-weighted cohort[24] (n=758). Both reported the most favorable economic profiles in the entire Category B dataset, HeartLogic with a per-patient cost reduction from €14,169 to €4,210 in the Belgian subgroup[18], and TriageHF Plus dominant over usual care in a lifetime Markov projection (saving £3,989 per patient) with 99.4% of probabilistic simulations cost-effective at the £20,000/QALY NICE threshold[24]. Both algorithm-based studies[18,24] reported the most favorable economic profiles in the Category B, but neither compared an active algorithm against the same CIED platform with the algorithm switched off.

Table 1.

DISCUSSION

Three novel findings emerge from this review. First, the economic evidence base is far narrower than the technological landscape it is assumed to cover: of all the monitoring technologies now in clinical use or late-stage development, only CardioMEMS, HeartLogic and TriageHF Plus have been evaluated economically in their own right. Second, the apparent cross-country spread in CardioMEMS ICERs is driven mainly by methodological convention rather than by real differences in clinical effectiveness, so headline ICERs are not comparable between jurisdictions as commonly assumed. Third, standalone sensors and CIED-resident monitoring have fundamentally different economic comparators, and separating them, as the two independent NICE appraisal programs also do, is what makes their economics interpretable.

For the cardiologist, the Category A evidence offers consistency rather than precision. Independent modelling groups using different trial datasets, cost inputs and national reporting conventions reach the same qualitative conclusion: PA pressure-guided management with CardioMEMS is an economically defensible use of resources in the United Kingdom, in those continental European jurisdictions where primary evidence exists (the Netherlands, Spain, and the four-country model of Cowie et al. 2017 covering Belgium, Germany, Italy and the Netherlands), and in the United States. This convergence aligns with

the technology's ESC Class IIb recommendation and FDA approval for NYHA Class II–III patients with prior hospitalization[6,28]. Two findings warrant particular emphasis. First, in the only US analysis reporting outcomes stratified by ejection fraction[12], CardioMEMS appeared to be more economically attractive in HFpEF than in HFrEF. The second is that the visible cross-country ICER spread is driven less by genuine differences in clinical effectiveness than by transparent methodological choices, device list price, discount-rate convention, and analytic perspective, meaning that head-to-head comparison of headline ICERs across jurisdictions is not as informative as it might first appear. The Argentine analysis (Alcaraz et al. 2021) is the only setting in which CardioMEMS is not cost-effective at current prices and underscores that the economic case is sensitive to device pricing relative to local healthcare unit costs; the implications for similarly positioned middle-income systems are direct.

The NICE HealthTech guidance[29] published in early 2026 provides the most rigorous single-payer reference point for the international economic evidence base. For Category A (CardioMEMS), NICE guidance HTG769 arrived at an updated independent base-case ICER of £31,264 per QALY gained using a lifetime Markov model, somewhat higher than the earlier published UK estimates of £19,274–£19,761 per QALY reviewed here, a difference attributable to revised utility assumptions and an upgraded monitoring cost assumption (band 7 prescribing nurse rather than band 5). Under a clinically realistic monitoring schedule, the ICER fell to £14,037 per QALY, well below the NHS cost-effectiveness threshold, leading NICE to conclude that CardioMEMS represents a cost-effective use of NHS resources. Cordella or other invasive hemodynamic monitor devices could not be appraised due to insufficient clinical evidence and was restricted to research settings,

illustrating that Category A status alone does not guarantee economic endorsement in the absence of adequate evidence.

For Category B, the take-home message is reassuring at a strategic level: across markedly different healthcare systems, no analysis found CIED-based remote monitoring to cost more than standard in-office follow-up, and most found it to save money. The mechanism, reduced inpatient admissions rather than displacement of clinic visits, aligns the economic case with the clinical rationale and should generalize across reimbursement models. Two clinically actionable points emerge for the cardiologist. The first is that absolute savings appear largest in CRT-D recipients, reflecting their higher baseline hospitalization risk; this argues for prioritizing remote-monitoring infrastructure in CRT-D programs when resources are constrained. The second is that the algorithm-based studies (HeartLogic, TriageHF Plus), while showing the most favorable economic profiles in the dataset, share a comparator limitation that matters in practice: neither was tested against the same CIED platform with the algorithm switched off. Deploying the algorithm without the associated staffing model has not been independently evaluated, and commissioners should plan accordingly. Future evaluations of algorithm-based monitoring should adopt conventional remote monitoring (same platform, algorithm off) as the prespecified comparator and, where feasible, randomize patients to algorithm-on versus algorithm-off conditions, a design that NICE HTG730 implicitly endorsed by recommending ongoing registry data collection.

For the algorithm-based subcategory of Category B, NICE guidance HTG730 (October 2024)[30] appraised TriageHF (the Medtronic risk-stratification algorithm in isolation) and

HeartLogic, finding both to have a 100% probability of cost-effectiveness at both £20,000 and £30,000 per QALY thresholds in probabilistic analysis. This is consistent with the dominant economic profiles reported in Ahmed et al. (2025), who evaluated TriageHF Plus, the same Medtronic algorithm coupled with a structured nurse-led telephone triage pathway, and Treskes et al. (2021). It is important to note that TriageHF (as appraised by NICE) and TriageHF Plus (as evaluated by Ahmed et al.) are related but distinct interventions: TriageHF Plus bundles the algorithm with a clinical response protocol whose contribution to the observed outcomes cannot be separated from the algorithm itself, and the dominant headline result for TriageHF Plus should therefore be interpreted as evidence for the combined intervention, not for the algorithmic layer in isolation. CorVue was actively not recommended by NICE due to inadequate diagnostic sensitivity and a high false-positive rate, and HeartInsight was restricted to research.

An equally important finding is what this review did not find. The search strategy was deliberately broad, covering pulmonary artery sensors (CardioMEMS, Cordella), left atrial pressure sensors (V-LAP, HeartPOD), inferior vena cava sensors (FIRE1/NORM), historical and discontinued platforms (Chronicle), impedance-only monitoring (OptiVol, CorVue), and multisensor algorithms (HeartLogic, TriageHF Plus); yet of all the named technologies, only CardioMEMS, HeartLogic, and TriageHF Plus generated peer-reviewed economic evaluations meeting eligibility criteria, alongside studies of generic CIED transmission platforms. Cordella and OptiVol appeared only bundled within, respectively, a mixed-device cohort[25] and the remote arm of a randomized trial[8], neither of which reported device- or algorithm-specific costs. Beyond device-level gaps, two population- and setting-level

evidence gaps deserve explicit acknowledgement. First, HFpEF is represented in only a single subgroup analysis[12], even though CardioMEMS is approved irrespective of ejection fraction in the US (whereas in Europe its guideline-based indication is currently restricted to HFrEF) and HFpEF accounts for roughly half of the prevalent HF population. Second, the only economic evidence from outside high-income settings comes from Argentina; no analyses were identified for Eastern European, Latin American (other than Argentina), African, Middle Eastern, or Asian healthcare systems, leaving a substantial portion of the global HF population without locally relevant economic data. From the complementary perspective of the healthcare payer or policymaker, the same evidence base reads differently: where robust cost-effectiveness data exist, they provide a rationale for reimbursement and for relaxing the restrictive utilization caps that currently limit access, whereas the pervasive evidence gaps justify caution in funding technologies whose economic value remains unproven.

Methodological heterogeneity across both categories remains a significant obstacle to synthesis and cross-setting comparison. Studies varied considerably in their time horizons (16 months to lifetime), perspectives (payer, NHS, societal, hospital), discount rates (not reported to 5% per annum), utility estimates, and hospitalization cost inputs. Future research should prioritize the development of category-specific reporting standards: Category A evaluations should standardize the approach to device longevity and monitoring frequency assumptions and report the device costs used; Category B evaluations of transmission platforms should consistently unbundle platform costs from device implant costs and report ICD and CRT-D subgroups separately; and Category B evaluations of advanced alert algorithms should specify conventional remote monitoring as the

prespecified comparator and report the clinical response protocol as a distinct intervention component.

LIMITATIONS

Several limitations of this scoping review merit acknowledgement. First, the two-category taxonomy proposed here is a contribution of this review rather than a pre-existing classification; while we believe it reflects clinically meaningful distinctions and is consistent with NICE's separate appraisal pathways for HTG769 and HTG730, alternative classifications are possible. Second, most of the included evidence is model-based: conclusions are only as valid as the structural and parameter assumptions on which the models rest. Third, the underlying efficacy and cost-effectiveness inputs are seldom derived from randomized or otherwise high-quality comparative data. Fourth, the search was restricted to PubMed and Scopus and the references of the included studies, and did not include a systematic grey-literature search, potentially missing some relevant articles. Fifth, search terms were formulated exclusively in English, and relevant non-English economic evaluations may therefore have been missed, which may have contributed to the under-representation of low- and middle-income settings noted above. Finally, publication bias may have over-represented economically favorable results, particularly for industry-sponsored evaluations; readers should weigh the predominance of "cost-effective" or "dominant" verdicts in the synthesis with this caveat in mind.

CONCLUSIONS

Both CardioMems and CIED-based remote monitoring are economically advantageous for heart failure management across multiple healthcare systems. CardioMEMS is cost-effective at accepted thresholds in the UK, continental Europe and the United States. It is not cost-effective in Argentina without a 10–25% price reduction. CIED-based remote monitoring is consistently cost-neutral or cost-saving. Savings are largest in CRT-D recipients. Both conclusions are supported by recent NICE guidance. Future research should prioritize standardized health-economic modeling, explicit separation of technology subcategories with distinct comparators, randomized algorithm-on versus algorithm-off designs, and dedicated evaluations in low- and middle-income countries to guide equitable global deployment.

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DISCLOSURES

Conflict of interest: none declared.

DATA AVAILABILITY STATEMENT

No new data were generated or analysed in support of this research.

CONSENT

This scoping review analyzed previously published, aggregated data from peer-reviewed studies and did not involve individual patient data or any identifiable patient information. Informed patient consent was therefore not applicable.

LEGENDS

Figure 1. PRISMA Flow-Diagram.

Alt text for figure 1: A flow chart showing the sequential stages of study selection, starting from initial database search records, moving through duplicate removal and abstract screening, and concluding with the final number of included studies.

Figure 2. CardioMEMS cost-effectiveness across countries. Panel A illustrates the Incremental Cost-Effectiveness Ratio (ICER) of the CardioMEMS device compared against a conventional $100,000 per Quality-Adjusted Life Year (QALY) benchmark. Panel B illustrates the ICER relative to the locally applied cost-effectiveness (CE) thresholds for each country.

Abbreviations: CE, cost-effectiveness; ICER, Incremental Cost-Effectiveness Ratio; QALY, Quality-Adjusted Life Year; USD, United States Dollar. Alt text: Two bar charts summarizing CardioMEMS cost-effectiveness. Panel A compares the cost per QALY against a $100,000 threshold for Spain, the Netherlands, the United Kingdom, the United

States, and Argentina. Panel B shows the cost per QALY as a percentage of the specific local cost-effectiveness threshold for those same countries.

Figure 3. CIED-based remote monitoring: per-patient cost saving across countries. The chart displays the annualized per-patient cost difference of remote monitoring versus in-office follow-up, converted to United States Dollars (USD) (GBP=1.27, EUR=1.08, PLN=0.25). Ranges indicate the minimum and maximum across studies per country; points indicate the median.

Note: Treskes 2021 (Belgium, HeartLogic) is a single-arm pre-post study without a concurrent control; de Graaf 2024 uses commercial-headroom values. Abbreviations: CIED, cardiac implantable electronic device; CE, cost-effectiveness; EUR, Euro; GBP, Great British Pound; PLN, Polish Zloty; RPM, remote patient monitoring; USD, United States Dollar. Alt text: A dot plot displaying the annualized per-patient cost savings of various CIED-based remote monitoring technologies across different countries, including Belgium, Germany, the United States, the Netherlands, Italy, Poland, and the United Kingdom. All values represent cost-neutral or cost-saving outcomes.

Table 1. Headline economic outcomes by study

Study	Country	Technology	Headline economic result	Verdict at local threshold
Cowie 2017	UK + 4 EU	CardioMEMS	ICER £19,274/QALY (UK); €22,555–€23,899/QALY (NL/BE/IT/DE)	Cost-effective at £20k threshold
Cowie 2023	UK	CardioMEMS	ICER £19,761/QALY; dominant in COAST real-world scenario	Cost-effective at £30k (81.9% PSA)

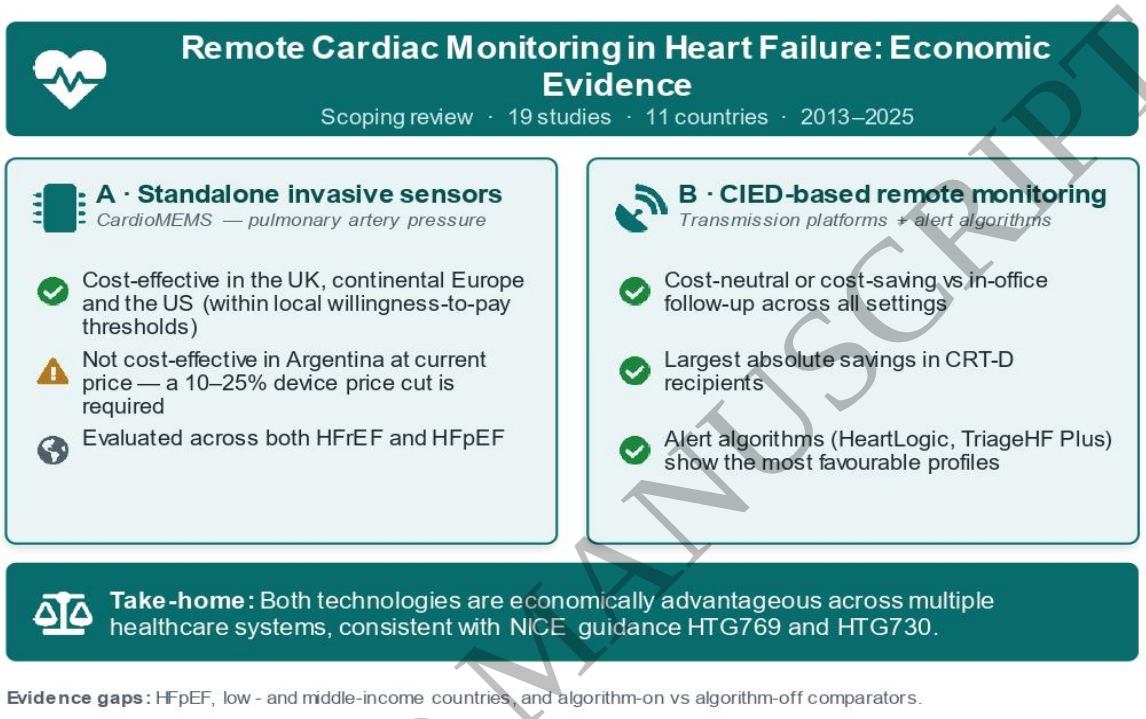
Mokri 2024	Netherlands	CardioMEMS (MONITOR-HF)	€10,406/QALY (healthcare); €20,753/QALY (societal)	Cost-effective at €50k (87% PSA)
Sandhu 2016	USA	CardioMEMS	$71,462/QALY overall; $47,768 HFpEF / $82,301 HFrEF	Cost-effective at $100k
Martinson 2017	USA	CardioMEMS	$12,262–$29,593/QALY across cost scenarios	Cost-effective at $50k
Schmier 2017	USA	CardioMEMS	$44,832/QALY; 49.6% vs 23.8% alive at 5 yrs	Cost-effective at $100k
Codina 2024	Spain	CardioMEMS (real-world)	Net benefit +€346 at yr 2; +€10,110 at yr 5; HFH HR 0.22	Cost-saving
Alcaraz 2021	Argentina	CardioMEMS	ICER 3–5× GDP per capita (above WHO threshold)	Not cost-effective; needs 10–25% price cut
Dauw 2022	BE/CH/UK	CardioMEMS + Cordella (real-world)	HF-related costs €6,286→€3,761 at 6 mo; €8,960→€6,167 at 12 mo; HF hospitalizations –50% at 6 mo	Cost-saving (no ICER; device cost excluded)

Kolominsky-Rabas 2016	Germany	CardioMEMS (population simulation)	114,805 hospitalizations avoided and €522m saved, 2009–2021	Cost-saving (no ICER; device cost excluded)
Zanaboni 2013	Italy	Medtronic CareLink (EVOLVO RCT)	+0.065 QALYs and –€888.10/patient over 16 mo	Dominant
Burri 2013	UK	Biotronik Home Monitoring	–£33/patient over 10 yrs; –51% inappropriate shocks	Cost-neutral
Capucci 2017	Italy	Multi-mfr CIED RPM (EFFECT)	–€115/patient-year (€757 vs €872, p<0.0001)	Cost-saving (largest in CRT-D)
Buchta 2017	Poland	Multi-mfr CIED RPM	–33.5% costs over 3 yrs; CRT-D subgroup –42.7%	Cost-saving
Boriani 2017	Italy (multinational RCT)	Medtronic CareLink (MORE-CARE RCT)	–€2,899 to –€12,496 per 100 patients over 2 yrs; healthcare resource use –38%	Cost-saving (no ICER)

Chew 2023	USA	Biotronik HM alert-only (TRUST)	–$1,677/patient over 2 yrs	Cost-saving
de Graaf 2024	NL/DE/FR	Boston LATITUDE RPM (REMOTE-CIED)	Commercial headroom: €881/2yr (NL); €5,005 (DE)	Cost-saving
Treskes 2021	BE/NL/CH	HeartLogic algorithm	HF hospitalizations 27→7; per-patient cost €14,169→€4,210 (BE)	Cost-saving (no ICER)
Ahmed 2025	UK	TriageHF Plus (algorithm + nurse pathway)	Dominant: –£3,989/patient lifetime; IRR 0.57 for HFH	Dominant; 99.4% CE at £20k

Headline result reproduces the bottom-line ICER, cost saving, or net benefit reported by each study; full methodological detail (perspective, time horizon, discount rate, comparator) is in Supplementary Material S5. Verdict reflects each study's own conclusion against the cost-effectiveness threshold conventionally applied in its jurisdiction (£20,000–£30,000/QALY in the UK, €50,000/QALY in the Netherlands, $50,000–$100,000/QALY in the US, 1–3× GDP per capita where WHO thresholds apply). Dominant = the intervention is more

effective and less costly than the comparator. CE = cost-effective; PSA = probabilistic sensitivity analysis; HFH = heart-failure hospitalisation; IRR = incidence rate ratio.



Graphical Abstract
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